Distribution Systems Reliability – Lakeland Electric Case Study

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Key Words: *Distribution Reliability, Distribution Automation, Protective Device, Feeder Reliability, Substation Reliability.*

SUMMARY & CONCLUSIONS

The case study presented in the paper combines the distribution substation and the distribution feeders in one analysis to evaluate the reliability of supply at a customer location. This approach provides a more realistic set of reliability indices, because it includes the outage impact of both distribution feeder(s) and the substation components. The indices can be used to rank needed reliability improvements on a feeder, multiple feeders and/or a substation. The installation of protective devices such as reclosers, breakers, fuses and sectionalizers is considered to be a generally accepted practice for improving reliability; however, it should be realized that additional components may also increase exposure to failures that could lead to degradation of reliability. In addition to the fact that more is NOT necessarily better, the distribution system is also subject to the law of diminishing returns. The goal is to find the optimal point where the addition of the next component adds value instead of subtracting value. Improving reliability does not mean more expense or capital investment. Customer reliability can be improved by optimal placement of protective and sectionalizing devices. It is important to identify areas in the system that experience more problems and require improvements to better serve customer needs.

Presently, Lakeland Electric keeps track of the historical performance of its customers by calculating SAIFI, SAIDI, CAIDI, and MAIFIe. As a customer responsive service provider, Lakeland Electric has started a proactive program to quantify indices for its customers. One of Lakeland Electric's capital budget priority criteria is to study and justify the benefits of proposed reliability projects to customer's reliability. The estimation of a customer's historical reliability and the prediction of future levels of reliability involve monitoring customer-circuit historical performance, and using customer-circuit connectivity based analytical method to estimate and predict future reliability levels. The analysis is useful as a means of meeting customer's expectations, while at the same time making judicious choices in selecting capital projects. The computed indices are useful in justifying capital expenditure to reinforce the system.

The reliability indices reported in this paper were calculated for the customers that are served by Palmetto Substation, one of the Lakeland Electric distribution substations. The indices are used in developing reliability initiatives and to rank various projects based on improvement in reliability as seen by a customer. *The main focus of this paper is to combine the substation and distribution feeders in the one analysis to evaluate the reliability of supply to the customer*. The paper discusses both customer-based indices such as SAIFI, SAIDI, CAIDI, MAIFIe, and energy based indices such as EUE, which can be used in selecting the best option from various alternatives available to a planner. Different conclusions are obtained if customer reliability is only quantified by modeling, without making due consideration of the tie support from neighboring feeders. It is expected that this analysis will help Lakeland Electric plan, design and operate the distribution facilities in a cost-effective manner while meeting its obligations to its customers, city council, and regulators.

1. INTRODUCTION

List of Acronyms:
ASAI Average Service Availability Index
CAIDI Customer Average Interruption Duration Index (customers minutes out per interruption)
CMI Customer Minutes of Interruptions
EOC Expected outage cost in dollars ($)
EUE Expected Unsupplied Energy (kWh per year)
O&M Operations and Maintenance
SAIDI System Average Interruption Duration Index (customers minutes out per year)
SAIFI System Average Interruption Frequency Index (interruptions per year)
MAIFIe Momentary Average Interruption event Frequency Index

The pressure to reduce energy costs, in addition to the impacts from environmental groups and regulatory bodies at both the national and local level, has forced the electric utilities to justify capital expenditure for reliability improvement. Customers are demanding a higher level of service and accountability from the electric service providers in terms of reliability and quality of service. Electric service providers are also accountable to regulators, who incorporate reliability measures such as "how often" and "how long" a customer can be interrupted in a year.

Since the distribution system links an end user to the utility's transmission and/or sub-transmission network, it is of fundamental importance to the overall electrical network of a utility company. From a customer's point of view, the important guiding factors for choosing an electric service provider are energy cost and system reliability. Customer supply reliability is dependent upon many factors (Ref. 1-5). Some of these factors are listed below:

1. **Bulk Supply Point Reliability**: Dependent on the grid reliability and includes generation, transmission and sub-transmission and sub-station reliability. Any improvement in bulk supply point reliability, directly impacts the end-users (customers) reliability that are connected to this point.
2. **Distribution System Reliability:** Encompasses the following major categories:
   - **Network design (planning) reliability -**Based on the components that provide a final link between the bulk supply point and the customer's electric system. Major components include breakers, reclosers, circuits, transformers, isolators & fuses.
   - **Network operational reliability-** Based on O&M practices followed by a utility, and includes utility switching schemes that minimize the impact of an outage.
   - **Environmental factors -** Includes major conditions that are beyond a utility's control; i.e., outages caused by earthquakes, cyclones and tornadoes. Although electric service providers strive to minimize the impact of these major events when they occur, it is obviously too costly and, as such, impractical to design a system for these rarely occurring events.
3. **Customer System Reliability** - Includes the customer's network, appliances, and backup measures (adopted under outage situations).

Both planning and operations reliability for a distribution system are important. If a utility does not have the facilities (both hardware and software) to supply power to its customers, no amount of O&M is going to improve the situation. Also having designed and built the most reliable system does not mean that it will not fail. Outages will occur but O&M practices followed by a company can help minimize both the frequency and duration of customer interruptions.

Predictive reliability assessment provides a basis to select the best options from several competing projects. Application of the historical outage data, obtained from a manufacturer or from fieldwork, can be used to study outages for the proposed network topology under changing load/customer demands, and this usually provides the optimal solution. The reliability indices computed by a predictive tool may not give the system performance in an absolute manner; however, it does provide information in order to compare various alternatives:

- What reliability improvements can be expected by implementing the proposed changes?
- Which initiative gives an optimal benefit to cost ratio?
- Or what changes should be made to a distribution system to attain the set targets? For example, if a utility wants to decrease its CMI by ten percent, then what facilities should be planned to meet the target.

Lakeland Electric undertook a pilot study to assess the benefit of using predictive reliability assessment methods to decrease customer outage minutes by at least 10%. The study was done using General Reliability's DIStribution RELiability (DISREL) program (Ref. 6). The objective was to develop specific plans to meet the target. If there is more than one option available, which is usually the case, then which option(s) should be implemented first? What is the payback period?

2. DISTRIBUTION SYSTEMS RELIABILITY PROGRAM

The program assists with predictive reliability assessment of a distribution network, including both feeders and distribution stations. It computes a set of reliability indices including SAIFI, SAIDI, ASAI, load/ energy curtailed and the cost ($) of outages based on the component outage data and the cost of interruption to a customer after modeling time-sequenced switching actions taken by an operator/repair-person following an outage event. Normally open transfer supply points (redundant supply, tie points) and the limitations on load transfer to other sources can be included. Typical outage data for major components and the cost of interruption data for different types of customer is supplied with the program. The data needed for the analysis is divided into four major categories:

1. Component data
2. Network (topology) data
3. Switching data
4. Component outage data

The component data file contains data for each component (objects) included in the study. The data includes ID, current, voltage and power ratings, failure rate, repair time, switching (isolation) time, maintenance rate and maintenance time.

The network data file contains the network topology information for the study system. All components specified in this file must already be defined in the component data file. The exact number of components that are included in the study is determined from the connectivity information given in this file. The switching instructions data file contains time-sequenced switching instructions that an operator/repair person takes following an outage event.

The reliability data file contains outage data for various components. This generic data is used for any missing data that is not supplied with the component data. Outage data specified in the component data file would be applicable to that component only.

3. RELIABILITY INDICES

The program computes a set of reliability indices that have been recommended in various publications (Ref. 1-3, 5). Some of the load point indices computed are as follows:

1. Frequency of load interruptions (occurrences per year)
2. Duration of load interruptions (hours per occurrence)
3. Duration of load interruptions (hours per year)
4. Frequency of customer interruptions (customer-interruptions per year)
5. Duration of customer interruptions (customer-hours per year)
6. Expected Unsupplied Energy (EUE in kWh per year)
7. Expected outage cost in dollars

The program also computes the following indices for the system under study:

1. System Average Interruption Frequency Index (SAIFI – interruptions per year)
2. System Average Interruption Duration Index (SAIDI - customers minutes out per year)
3. Customer Average Interruption Duration Index (CAIDI- customers minutes out per interruption)
4. Average Service Availability Index (ASAI)
5. Expected Unsupplied Energy (EUE in kWh per year)
6. Expected outage cost in dollars ($)

These indices can be utilized to obtain important information:

1. establishes the chronological changes in system performance, and therefore assisting in the identification of weak areas and the need for reinforcements,
2. establishes existing indices that serve as a guide for acceptable values in future reliability assessments,
3. enables previous predictions to be compared with actual operating experience,
4. satisfies performance-based ratemaking goals set by utilities or by regulators,
5. quantifies reliability benefits of distribution automation

4. RELIABILITY CASE STUDY

Reliability studies reported in this paper are given for the area that is served by Palmetto station. The indices are calculated using the default outage data and do not represent the true performance of the supply reliability. The main objective of the study is to evaluate the applied techniques and methodologies for the future reliability analysis of Lakeland Electric's feeders under its distribution automation initiative. This will help in developing reliability initiatives to improve the area reliability. Reliability indices, which are included in this report, are calculated by adding protective devices and/or replacing switches with automated protective devices. The study is conducted as a part of distribution automation initiative to improve customer reliability.

4.1 Area Map and Details

An electric map of the Palmetto distribution substation and the feeders served from this station is shown below.

4.2 Reliability Improvement due to Distribution Automation

Normally one would expect that the feeder reliability increases if a fuse or a breaker is added. The reliability improvement depends on where the component is added. The main objective is to quantify changes in customer reliability corresponding to component additions. However, it should be noted that a greater number of components might lessen customer reliability, as a result of failures due to the additional components. A balance must be sought between reliability improvement and additional expenditure, corresponding to increased component failure rate, in order to maintain an effective optimal reliability level.

The placement of switches on a distribution feeder is not solely a function, controlled by reliability considerations. Switches are placed for load balances, in addition to providing ease of maintenance. The recommendations made in this report do not consider any factor other than reliability. The basis for adding new components is as follows:

1. It should improve the feeder reliability. This means that the design index should decrease after adding the new component(s).
2. Savings in the outage costs and/or improvements in the feeder reliability justify the cost of adding new component(s).

In order to examine various options, a brute force approach was used in adding protective devices. The following steps were taken:

1. Compute reliability indices for the existing distribution system.
2. Replace a switch by a breaker. For each option, reliability indices were computed.

This brute force approach of examining a large number of scenarios does not require any optimization/selection techniques to reduce the computing time. The main advantage of using a computer program is to examine all credible outages for a number of scenarios.

5. DISCUSSION

Various reliability indices for the area served from Palmetto substation are given in Table 1. There is a small improvement in reliability indices if a breaker replaces an existing switch. Indices are calculated after transferring load to neighboring feeders whenever it is possible to do so. If only one feeder is modeled and the transfer of load to other feeders not considered, then the feeder automation greatly improves the reliability indices. Reliability indices for Feeder A334 are given in Table 2. For example, the improvement in SAIFI is 8% as compared to the existing feeder if switch U104 is replaced by a breaker. SAIDI decreases by 4.5%, both EUE and outage costs decrease by 18%. Results obtained in this analysis raise an interesting question: *Which system modeling should be used for making a decision?*

In our opinion modeling only one feeder and not considering load transfer does not provide a complete solution and may not rank reliability initiatives correctly. It is more realistic to examine area reliability by including all feeders and substations that serve the area.

The ranking of options is dependent on the design index and it can change if a different index is chosen as a design index. This is not a concern but it highlights the fact that changes in a feeder react differently in meeting reliability guidelines. It is the type of customer who should be the deciding factor in selecting a particular option. There is also no reason to use a uniform index throughout the system. The optimal level of reliability is decided by the regulatory requirements, competition, and the cost incurred in providing facilities. The predictive analysis used in the case study presented here provides a methodology to address only reliability issues.

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Table 1: Improvement in indices for area served from Palmetto substation due to automation

Option	SAIFI	SAIDI	CAIDI	ASAI	EUE	EOC
Existing System	1.27553	375.4	294.3	0.999286	87538	437691
Replace U104 by breaker	1.27508	375.3	294.3	0.999286	87115	435576
Replace S345_A334 by breaker	1.27496	375.3	294.4	0.999286	87195	435977
Replace S1131 by breaker	1.27514	375.3	294.3	0.999286	87301	436505

Table 2: Improvement in indices for area served by Feeder A334 due to feeder automation

Option	SAIFI	SAIDI	CAIDI	ASAI	EUE	EOC
Existing System	0.13599	32.9	241.9	0.999937	2323	11613
Replace U104 by breaker	0.12475	31.4	251.8	0.999940	1899	9494
Replace S1131 by breaker	0.12618	31.7	251.2	0.999940	2085	10424
Add breaker to AA11	0.11510	30.3	263.5	0.999942	2136	10682

Fig.1: Palmetto Distribution Substation

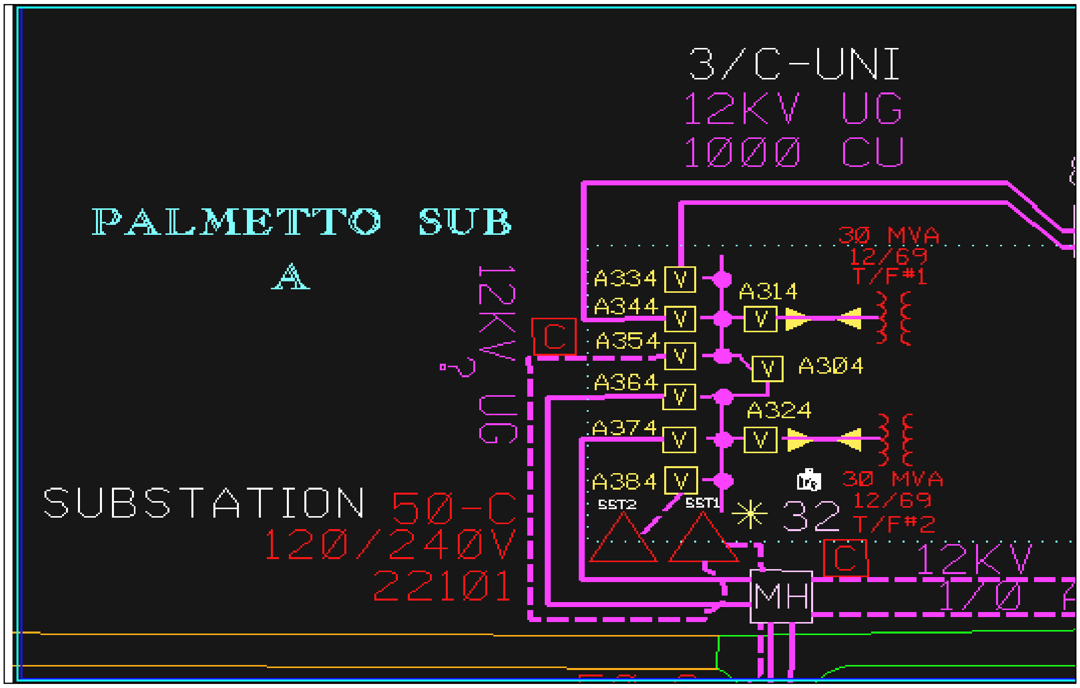

Figure 2: Palmetto circuit A-334 serves downtown Lakeland and some small commercial customers. Total connected loads are 9,555KVA.